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Response of three rice (*Oryza sativa*) cultivars to pendimethalin application, planting depth, and rainfall

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Abstract

Greenhouse experiments were conducted to evaluate the response of three rice cultivars (Lemont, Cocodrie, and Wells) to pendimethalin as a function of planting depth, herbicide application timing, and timing of simulated rainfall after herbicide application. In the absence of pendimethalin, emergence of Wells was greater than that of either Cocodrie or Lemont. However, regardless of application timing, Wells was more sensitive to pendimethalin compared to either Cocodrie or Lemont. Emergence of all cultivars was reduced by pendimethalin at planting depths <3.8 cm. For all cultivars, optimal planting depth for emergence and reduced injury was 0.64–1.9 cm. Rainfall after pendimethalin application, regardless of amount or timing, had no effect on rice emergence or plant health. Root biomass was not affected by planting depth or pendimethalin application, regardless of application timing. Based on these data, pendimethalin should be applied at labeled rates between 3 and 7 days after planting of certain cultivars, and should not be applied to fields planted to the Wells cultivar. A planting depth that will optimize rice emergence should take precedence over a depth that will minimize injury caused by pendimethalin.

Keywords: Flooded rice; Herbicide; Herbicide tolerance; Rice injury; Simulated rainfall

1. Introduction

[*Echinochloa crus-galli* (L.) Beauv.] (barnyardgrass) and [*Leptochloa fascicularis* (Lam.) Gray] (bearded sprangletop) are highly competitive in southern US rice fields. Both weeds are capable of decreasing rice yields by 70% and 36%, respectively (Smith, 1983). Carey et al. (1994) reported that *L. fascicularis* caused up to a 50% reduction in rice yield for the cultivar 'Lemont'.

Clomazone, quinclorac, and thiobencarb are the only labeled herbicides that have pre-emergence activity on grass weeds that are common in flooded rice fields in the southern US (Anonymous, 2005). Quinclorac, though it can be applied to rice at planting, has no activity on *L. fascicularis* when applied pre- or post-emergence. Both pendimethalin and thiobencarb provide excellent control of *L. fascicularis*, but the rice seed must have imbibed water prior to application. Clomazone can be applied at planting and provides excellent control of this weed (Anonymous, 2005).

With low rice prices, growers continue to seek ways to decrease production costs. Currently, herbicides account for approximately 17% of the variable costs associated with producing rice (Anonymous, 2003). At current prices, pendimethalin costs approximately 68% less than clomazone or thiobencarb (Anonymous, 2005).

Street and Lanham (1996) evaluated the effects of applying pendimethalin to 'Lemont' rice on conventional-tilled Sharkey clay (very-fine, smectitic, thermic Chromic Eqiaquert). Over a 2-year period, rice injury ranged from 28% to 63% for 1.12 to 2.24 kg ai/ha doses when assessments were made 2 weeks after application.

Flushing, a common practice in rice production, is defined as applying water across a planted rice field prior to germination in order to imbibe rice seed and facilitate

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emergence. Flushing is also conducted after emergence to aid in rice seedling survival until the plants become established. Street and Lanham (1996) reported that when pendimethalin was applied 1, 4, or 7 days after flushing, injury to 'Lemont' rice ranged from 0% to 30%. Rice yields were decreased by the pre-emergence application of pendimethalin in one of the 2 years compared to applications being made after flushing.

Though Lemont was one of the most popular cultivars planted from the late 1980s through the 1990s, other cultivars with greater yield potential have been released and now account for the majority of the rice hectareage. In the southern US Cocodrie and Wells are the most popular semi-dwarf and conventional-stature long grain rice cultivars in the southern US, respectively. Both cultivars exhibit excellent seedling vigour which allows growers to plant these cultivars deeper into the seedbed. In 2004, 'Cocodrie' was planted on approximately 30% of the southern US rice hectareage, while 27% of the hectareage was planted to 'Wells' (University of Arkansas, 2004; Louisiana State University, 2004; Kanter et al., 2005; University of Missouri, 2004; Texas A&M University, 2004).

More producers are adopting conservation tillage practices which include no-till and minimum-till. Minimum tillage includes cultivation that is conducted in the fall or early spring prior to planting, but no soil disturbance occurs immediately prior to planting. The combination of planting cultivars with excellent seedling vigor into non-disturbed soils with greater available soil moisture may provide an opportunity to use pendimethalin as a pre-emergence herbicide for rice production and cause less injury. Planting seed deeper should enable the seed to imbibe prior to contact with pendimethalin. Additionally, information on tolerance of recently released cultivars (Cocodrie and Wells) to pendimethalin is needed. Therefore, the objectives of this research were to investigate the response of three rice cultivars to pendimethalin as related to planting depth, timing of application, and rainfall timing after herbicide application.

2. Materials and methods

2.1. General information

Greenhouse experiments were conducted in 2004 at the USDA-ARS Jamie Whitten Delta States Research Center in Stoneville, MS. Seeds of the rice cultivars Cocodrie, Lemont, and Wells were treated with 0.02 g ai mefenoxam/kg seed prior to planting for protection against seedling diseases. The seeds were obtained from commercial seed lots that were available for purchase by growers. Fifteen seed of each cultivar were planted in individual 11-cm diam plastic pots containing a Bosket sandy loam (fine-loamy, mixed thermic Molic Hapludalf). Seed were planted at varying depths depending on the experiment, and pots were maintained in a greenhouse with 32/25 °C (+3 °C) day/night temperature. Natural light was supplemented with light from sodium vapor lamps to provide a 14-h photoperiod. Pots were sub-irrigated with deionized water to field capacity to imbibe seed and initiate germination. After emergence, plants were sub-irrigated once every 2 days with deionized water. A 1% Hoaglands nutrient solution was added to the water on every other irrigation timing.

2.2. Planting depth and pre-emergence pendimethalin experiment

An experiment was conducted to evaluate the effects of planting depth and pre-emergence pendimethalin application on rice emergence and shoot and root biomass. An experiment with a factorial arrangement of treatments was conducted. Factors included cultivar, planting depth, herbicide application, simulated rainfall amount, and rainfall timing after herbicide application. Seed of each cultivar were planted in individual pots at depths of 0.64, 1.9, and 3.8 cm, respectively. Pendimethalin (Prowl 3.3 EC, BASF Corporation, 100 Campus Drive, Florham Park, New Jersey, 07932) at 1.1 kg/ha was applied over-the-top of half of the pots for each cultivar immediately after planting and sub-irrigation. Pendimethalin was applied with a CO_2-pressurized backpack sprayer equipped with TeeJet 8002 standard flat fan spray tips (Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188) delivering 94 L/ha water at 150 kPa. Half of the pots for each cultivar were not treated with herbicide (no herbicide). A simulated rainfall of 0.64 or 2.54 cm (7.5 cm/h intensity) was applied, using an indoor rainfall simulator, at 0, 1, 3, or 7 days after planting (DAP). The 0 DAP pots received rainfall immediately after pendimethalin application. The rainfall simulator was set to deliver droplets at a height of 2 m, and the actual amount of rainfall received was measured at the plant level with rain gauges. Plants were returned to the greenhouse immediately after rainfall application. Untreated and pendimethalin-treated pots of each cultivar and each planting depth with no rainfall were also included.

The number of emerged shoots per pot was determined at 8 and 21 DAP. Total fresh weight of aboveground shoot and root biomass from each pot was measured at 21 DAP. Above ground shoot biomass was clipped at soil level and weighed. Root biomass was removed from soil with water, seed hulls were removed, and root tissue was hand-dried with paper towels and weighed. Emergence data were presented as the percent of seedlings that emerged out of a possible 15 seed/pot. Shoot and root data were expressed as percent shoot or root biomass reduction per plant compared to respective non-pendimethalin-treated plants. The experimental design was a randomized complete block design with treatments replicated four times. Treatments were arranged in a factorial design with factors of cultivar, planting depth, herbicide application, simulated rainfall amount, and rainfall timing after herbicide application.

Data were pooled across experiments because of absence of experimental interactions.

2.3. Pendimethalin application timing experiment

Based on results of the previously described experiment, in which optimal emergence was observed at a planting depth of 1.9 cm, seed of each cultivar were planted in pots at a depth of 1.9 cm. Pendimethalin at 1.1 kg/ha was applied to pots at 0, 1, 3, or 7 DAP for each cultivar as described previously. The 0 DAP pots were treated immediately after planting and sub-irrigation. Untreated pots (no herbicide) were included for each cultivar. Plants were returned to the greenhouse immediately after pendimethalin application. Emergence and shoot and root biomass data were collected at 21 DAP as described previously in the planting depth and pre-emergence pendimethalin experiment. The height of a randomly selected plant was measured for each pot at 14 DAP. The experiment was conducted in a randomized complete block design with a factorial arrangement of treatments. Factors included cultivar, pendimethalin dose (0 or 1.1 kg/ha), and pendimethalin application timing. Treatments were replicated four times and the experiment was repeated. Data were pooled across experiments because of the absence of experimental interactions.

2.4. Statistical analysis

Data were tested for homogeneity of variance by plotting residuals. An arcsine square root transformation was performed before analysis but did not improve variance homogeneity. Thus, non-transformed data were used in analysis and presentation. Data were subjected to Analysis of Variance using the mixed model procedure in SAS (Statistical Analysis Systems (SAS), 2001). Means were separated using Fisher's protected LSD test at $P<0.05$.

3. Results and discussions

3.1. Planting depth and pre-emergence pendimethalin experiment

Rice emergence data were averaged across simulated rainfall amount and timing after planting as there were no effects or interactions. Emergence of all cultivars in the absence of pendimethalin increased an average 24–27 percentage points, respectively, between 8 and 21 DAP (Table 1). Planting depth had a significant effect on emergence of all cultivars at 8 DAP. The decrease in emergence with increasing planting depth at 8 DAP was most drastic on Lemont with 63% and 27% emergence at planting depths of 0.64 cm and 3.8 cm, respectively. By 21 DAP, planting depth had no effect on emergence of Cocodrie and Wells. Overall, planting depth had minimal effects on final emergence of all three cultivars, with only Lemont showing reduced emergence with increasing planting depth at 8 and 21 DAP. However, inconsistent or uneven initial emergence (8 DAP) from planting too deep may have some effect on stand uniformity, consistency in maturity, and subsequent milling quality. A uniform and consistent emergence of a rice stand is desired to minimize management complications and differences in milling quality caused by maturity differences across a field. In order to optimize emergence and reduce the risk of an uneven rice stand, all cultivars evaluated should be planted 0.64–1.9 cm deep.

Data for shoot and root weight in the absence of pendimethalin were averaged across cultivar and simulated rainfall timing and amount, as these factors had no effects

Table 1
Effects of planting depth on emergence of 'Lemont', 'Cocodrie', and 'Wells' rice at 8 and 21 days after planting (DAP)[a]

Planting depth (cm)	8 DAP				21 DAP			
	Cultivar							
	Lemont	Cocodrie	Wells	Average	Lemont	Cocodrie	Wells	Average
% emergence[b]								
0.64	63	55	67	62	77	71	84	77
1.9	51	47	57	52	78	70	82	77
3.8	27	32	49	36	68	66	80	71
Average	47	45	58		74	69	82	
$LSD_{0.05}$ (planting depth)[c]	4				3			
$LSD_{0.05}$ (cultivar)[d]	4				3			
$LSD_{0.05}$ (planting depth × cultivar)[e]	7				5			

[a]Data averaged across rainfall amount and rainfall timing after planting due to no significant effects or interactions. Means presented for no-herbicide treatments only.
[b]Percent of seedlings that emerged above soil line. (15 seed were planted in each pot).
[c]LSD may be used for comparison of mean values for planting depth, averaged across cultivars.
[d]LSD may be used for comparison of mean values for cultivars, averaged across planting depth.
[e]LSD may be used for comparison of mean values for cultivar by planting depth combinations (across rows and columns).

or interactions on shoot or root weights. Planting depth in the absence of pendimethalin had no effect on root weight of individual plants (Fig. 1). Shoot weight of all cultivars was reduced only slightly with increasing planting depth.

Data for rice emergence in the presence of pendimethalin were averaged across simulated rainfall timing and amount as these factors had no effect on reduction in emergence of any cultivar. Pendimethalin applied at planting reduced overall emergence by 21 DAP of all cultivars 15–24% (Table 2). Planting seed deeper did reduce the degree of reduction in emergence from 25% at the 0.64-cm planting depth to 13% for seed planted 3.8 cm deep. Emergence of Wells was most affected by pendimethalin with 24% reduction in emergence, compared to 15% and 16% reduction for Lemont and Cocodrie. However, applying pendimethalin at planting and not later for all cultivars evaluated does pose a risk with respect to reduction in emergence and subsequent stand reduction.

Data for shoot weight of rice plants in the presence of pendimethalin were averaged across simulated rainfall timing and amount as these factors had no effect on reduction in shoot weight of any cultivar. Pendimethalin applied at planting decreased shoot weight of all cultivars by 21 DAP (Table 3). Shoot weight for Wells was most affected by pendimethalin application, with 48% reduction in per plant shoot weight of Wells compared to 25% and 20% reduction for Lemont and Cocodrie. Reduction in shoot weight decreased with increasing planting depth for all cultivars. However, planting seed of all cultivars at a depth of 3.8 cm still resulted in a 17% reduction in shoot weight when averaged across all cultivars. Fresh weight of roots for all cultivars was not affected by pendimethalin applied at planting (data not shown).

Overall, increasing planting depth decreased initial emergence of all cultivars. Final stand counts for Lemont were reduced at the deepest planting depth, with other cultivars compensating for an initial reduction in emergence at the 3.8-cm planting depth and obtaining similar emergence levels across all planting depths. Pendimethalin

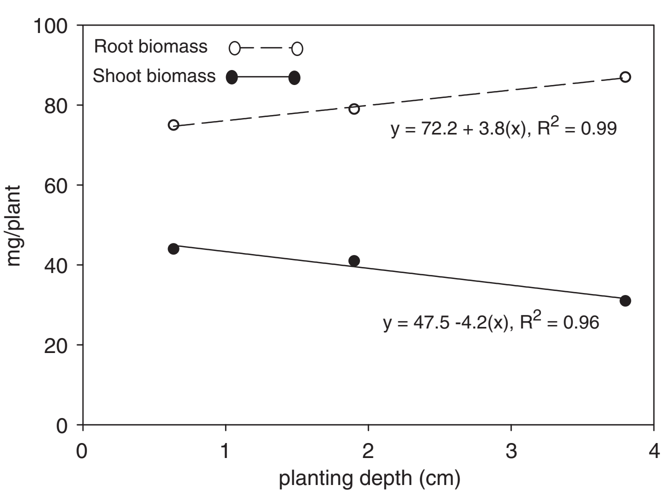

Fig. 1. Effects of planting depth on fresh weight of shoot and root biomass of three rice cultivars at 21 days after planting. No pendimethalin treatments. Data averaged across cultivars because no cultivar by planting depth interaction. Data averaged across rainfall timing and amount because no effect or interaction for either variable.

Table 2
Effects of pendimethalin (1.1 kg/ha) applied immediately after planting and planting depth on reduction in emergence of 'Lemont', 'Cocodrie', and 'Wells' rice at 21 days after planting[a,b]

Cultivar	Planting depth (cm)			
	0.64	1.9	3.8	Average
% reduction[c]				
Lemont	24	12	9	15
Cocodrie	23	14	11	16
Wells	29	24	18	24
Average	25	17	13	
$LSD_{0.05}$ (Cul.)[d]		4		
$LSD_{0.05}$ (PD)[e]		4		
$LSD_{0.05}$ (Cul. × PD)[f]		7		

[a]Abbreviations: Cul., cultivar; PD, planting depth.
[b]Data were averaged across rainfall timing and amount of rain after planting due to no interactions.
[c]Percent reduction with respect to comparable no herbicide treatment within each replication.
[d]LSD may be used for comparison of mean values for cultivars, averaged across planting depth.
[e]LSD may be used for comparison of mean values for planting depths, averaged across cultivar.
[f]LSD may be used for comparison of mean values for cultivar by planting depth combinations.

Table 3
Effects of pendimethalin (1.1 kg/ha) applied immediately after planting and planting depth on reduction in fresh shoot-weight of 'Lemont', 'Cocodrie', and 'Wells' rice at 21 days after planting[a,b]

Cultivar	Planting depth (cm)			
	0.64	1.9	3.8	Average
% reduction[c]				
Lemont	47	18	9	25
Cocodrie	39	15	7	20
Wells	67	40	36	48
Average	51	24	17	
$LSD_{0.05}$ (Cul.)[d]		6		
$LSD_{0.05}$ (PD)[e]		6		
$LSD_{0.05}$ (Cul. × PD)[f]		10		

[a]Abbreviations: Cul., cultivar; PD, planting depth.
[b]Data were averaged across timing and amount of rain after planting due to no interactions.
[c]Percent reduction with respect to comparable no herbicide treatment within each replication.
[d]LSD may be used for comparison of mean values for cultivars, averaged across planting depth.
[e]LSD may be used for comparison of mean values for planting depths, averaged across cultivar.
[f]LSD may be used for comparison of mean values for cultivar by planting depth combinations.

applied at planting reduced emergence and fresh weight of shoots of all cultivars evaluated. Planting seed of all cultivars deeper did lessen emergence and fresh weight of shoots due to pendimethalin. Wells was most sensitive to pendimethalin, and was best suited to deeper planting depths compared to Lemont and Cocodrie. As previously mentioned, Wells has a conventional-stature growth habit. It has been suggested that rice tolerance to pendimethalin may differ based on mesocotyl length. Sullivan and Merkele (1980) have suggested that cultivars with shorter mesocotyls may be more tolerant to pendimethalin than those with more elongated mesocotyls. The coleoptile nodes of semi-dwarf cultivars develop deeper below the soil surface compared to conventional stature cultivars. This may explain the difference in tolerance observed with the two semi-dwarf cultivars Lemont and Cocodrie compared to Wells.

3.2. Pendimethalin application timing experiment

Timing of pendimethalin application affected emergence of Wells, with an increasing degree of reduction in emergence as the time interval between planting and pendimethalin application decreased (Fig. 2). Timing of pendimethalin application had no effect on reduction in emergence of Cocodrie and Lemont cultivars, with 5–12% and 10–18% reduction to Cocodrie and Lemont, respectively, regardless of timing of pendimethalin application. Seed were imbibed by 1 DAP and had visual sprouts protruding from the seed by 4 DAP (personal observation). A significant decrease in reduction in emergence of Wells as the time interval between planting and pendimethalin application increased can be attributed to the seed being imbibed and sprouting by the time pendimethalin was applied at 3 or 7 DAP. A labeled late pre-emergence application of pendimethalin typically occurs during the 3–7 DAP window.

Reduction in plant height (Fig. 3) and fresh weight of shoots (Fig. 4) of all cultivars increased as the time period between planting and pendimethalin application decreased (Fig. 3). The degree of reduction in plant height and fresh weight of shoots of the 'Wells' cultivar was greater when compared to the other cultivars. Applying pendimethalin between 0 and 3 DAP of Cocodrie and Lemont resulted in significant reduction in plant height and shoot fresh weight. Reduction in plant height can delay timing of permanent flood that subsequently can result in additional weed flushes that must be controlled with post-emergence herbicides. Fresh weight of roots for all cultivars was not affected by pendimethalin, regardless of application timing (data not shown).

Planting seed of all cultivars deeper lessened the reduction in emergence caused by pendimethalin. However, planting seed deeper also delayed overall emergence,

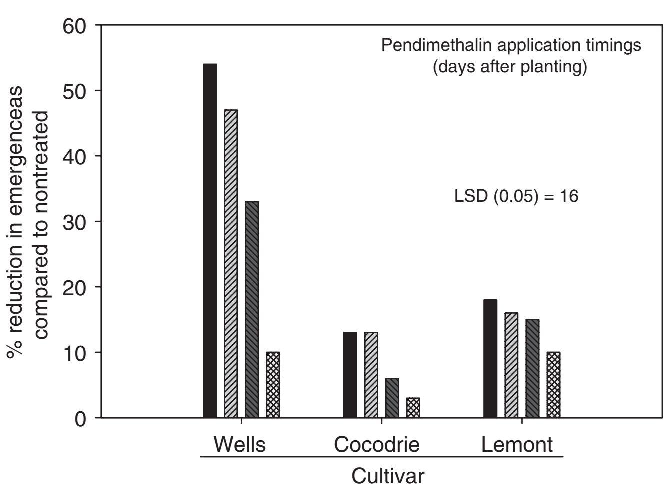

Fig. 2. Effect of pendimethalin (1.1 kg/ha) applied at 0, 1, 3, or 7 days after planting on reduction in emergence of rice cultivars at 10 days after planting.

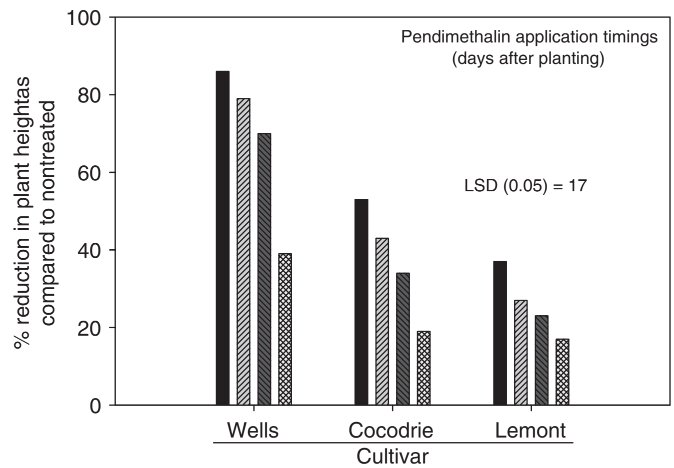

Fig. 3. Effect of pendimethalin (1.1 kg/ha) applied at 0, 1, 3, or 7 days after planting on reduction in plant height of different rice cultivars at 14 days after planting.

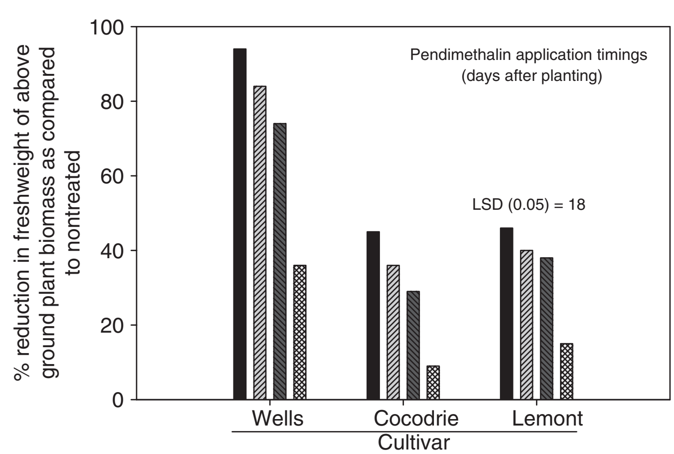

Fig. 4. Effect of pendimethalin (1.1 kg/ha) applied at 0, 1, 3, or 7 days after planting on reduction in fresh weight of aboveground plant biomass of different rice cultivars at 21 days after planting.

which can cause non-uniform stands and subsequent reduction in milling quality. The planting depth for all cultivars that resulted in reduction in emergence and degree of injury from pendimethalin to be less severe was between 0.64 and 1.9 cm. Wells withstood planting deeper better than Cocodrie and Lemont. However, Wells was much more sensitive to pendimethalin, regardless of application timing, when compared to Cocodrie and Lemont. Based on these data, pendimethalin should not be applied to fields that have been planted with Wells. In order to minimize injury to Cocodrie and Lemont, pendimethalin should be applied between 3 and 7 DAP. Rainfall after pendimethalin application, regardless of simulated rainfall amount or timing, had no effect on rice emergence or plant health. Thus, the timing or amount of a rainfall event in rice fields treated with pendimethalin should have no or minimal effect on rice. The fact that root biomass was not affected by planting depth and pendimethalin application, regardless of application timing, may help rice in overcoming initial reduction in emergence and may aid rice in compensating for early season reduction in shoot weights. Field research evaluating effect of application timing and dose of pendimethalin applied to various rice cultivars is needed to address this question.

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